

PROJECT DESCRIPTION

Introduction

Nearly every satellite that has entered space relies on positive fuel turn-on or shutoff brought about by pyrovalves. And whenever a pilot may need to eject from a disabled aircraft, pyrotechnically actuated systems plays a part in their safe return to earth. The Space Shuttle, for example, counts on over 300 such components to complete its mission. When there is no second chance, the "absolute reliability" requirement in ordnance standards make pyrovalves the first choice of high technology military and civilian aircraft.

But sometimes even the first choice is suspect. Launched successfully on September 25, 1992 by Titan IIIe-TOS from Cape Canaveral, the Mars Observer spacecraft cruised well right up to Mars, but lost contact just at its arrival on August 21, 1993, when it was to ignite its thrusters to enter Mars orbit. The fate is unknown: it may have blown up during ignition, been destroyed by meteorite, or simply frozen after having lost orientation. Some early speculation blamed a malfunctioning pyrovalve [1], two of which were commanded to fire just prior to loss of signal. Later analysis seemed to focus on the system clock [2], or oxidizer leaking through check valves [3], but most analysts agree that tangible evidence to support any particular scenario is unlikely to be recovered. The forensic evidence of pyrovalve failure is better documented, however, for both Telstar 402 [4] and Landsat 6 [5].

Thus, pyrovalves still warrant careful description of their operating characteristics, which is consistent with the NASA mission - to assure that both testing and flight hardware perform with the utmost reliability. So, until the development and qualification of the next generation of remotely controlled valves, in all likelihood based on shape memory alloy technology, pyrovalves will remain ubiquitous in controlling flow systems aloft and will possibly see growing use in ground-based testing facilities.

In order to assist NASA in accomplishing this task, we propose a three-phase, three-year testing program. Phase I would set up an experimental facility, a 'test rig' in close cooperation with the staff located at the White Sands Test Facility in Southern New Mexico. Its function is to obtain displacement, velocity and acceleration of the various pyrovalve

components as deemed necessary. Following the verification of the new test rig is Phase II in which a similar set of tests shall be conducted using pyrovalve components that have been subjected to environments similar to those encountered at Stennis Space Center. The objective here is to assist Stennis in delineating the trades in converting some of the multi-use valves (used at present in the propulsion testing facilities) to one-use 'disposable' pyrovalves. Phase three makes use of a modern machining facility M-TEC [6], located on the NMSU campus, whose precision capabilities would be brought to bear. The M-TEC task is to fabricate the test specimens as required in the proposed pyro valve testing program. The valve components would include those fashioned from standard materials, and also those machined from some of the newer materials and with improved sealing ram recently taken under consideration at WSTF [7].

Pyrovalve issues

Some of the potential problems associated with current pyrovalve technology include the blow-by of igniter combustion products, which may result in contamination of the flow system following a successful ignition, and also the level of mechanical impulse delivered to the piping and support systems as the ram is rapidly accelerated and subsequently brought to rest.

One common effect of ignition is the pyrovalve housing's small but apparently significant deformation. Both thermal and internal pressure loads tend to distort the housing in a transient and as yet undetermined shape. In an effort to characterize the associated blow-by event, the pyrovalve housing, and perhaps the ram, shall be instrumented. The extent to which this is necessary will be determined as a part of the project, but in any event, the housing may be outfitted with an array of accelerometers as well as a series of strain rosettes. These technologies are mature, and should pose relatively small difficulties in implementing. Coupling their outputs to a high-speed a/d card or digital storage oscilloscope will allow for the required measure of post processing.

Another technology, whose efficacy will be determined as a part of this project, is the recently available, off-the-shelf, laser displacement meter. An array of these sensors, which are

designed for a variety of displacement ranges, sensitivities, and data rates, may be placed about the pyrovalve housing to gage its displacement upon actuation. The number and placement of these sensors will be determined as a part of the testing program. If it's deemed necessary, another set of piezoelectric sensors can be used to determine the static pressure at the interior surface of the ignitor chamber.

Requiring about 1 millisecond for the ram to fully displace, the ram and valve housing positions may be gauged times at the (laser displacement sensor manufacturer) advertised 50-100kHz [cf., <http://my.netian.com/~miraeeng/sensor/lc3.htm>] update rate. We believe that this level of resolution is adequate to determine the ram position and/or the valve housing surface distortion necessary to infer some significant aspects of physics driving the blow-by process. Given the rapid advancements in this technology, by the time the project is underway, the laser displacement meter metrology may become sufficiently advanced that data rate limitations become insignificant. An eddy current proximity sensor [cf., <http://www.sentec.co.jp/us/henni.htm>], which typically operates at higher speeds, may also prove to be the required technology. Adaptation of the appropriate sensing technology is a primary intent of this proposal.

Following the data acquisition process, we surmise that a simplified model of the transient action of the housing may be approximated using a few basic assumptions. Given the ram position and velocity, we may begin by assuming adiabatic expansion of the initiator charge along with a frictionless sliding of the ram. After differentiating the ram position twice, we will estimate the average pressure that the detonation places on the ram. If we assume that the initiator chamber is subjected, at a minimum, to the average pressure calculated above, then we can deduce the distortion of the housing based on whether we choose to model the system as a thin- or thick-wall cylinder. In any event, the difference between the measured distortion and the calculated distortion should provide a guide as to which type of experiments to run in order to better define the model. The finite element method, a model for which has been developed in Pro-Mechanica at WSTF, as well as a standard CFD (computational fluid dynamics) code will be used at this time to guide the succeeding experiment design.

Thermal effects and the propagation velocity of the shock wave through the housing will not be taken into account during the initial experiments. Whether these parameters prove significant shall be determined.

A second area of investigation is the use of pyrovalves as disposable items in ground-based propulsion testing facilities. The conversion from the current re-usable valves to pyrotechnically actuated, one-shot valves is under consideration owing to the problem of cleaning the toxic propellants from permanent system components in preparation for successive tests. Thus a logical application of the technology developed above is to gage the effects of the new installation on valve operation. We intend to work closely with personnel at Stennis to determine the effects of corrosion and stress corrosion using the pyrovalve designs under consideration for adoption in the propulsion testing facilities.

Finally, advanced pyrovalve designs, those employing metal-to-metal seals, rather than the customary o-ring for example, may prove a desirable alternative to the commonly occurring blow-by and the subsequent contamination of flowing media by combustion products and shavings. The new designs, which shall be selected in close cooperation with both WSTF and Stennis, will be manufactured at NMSU's machining center, M-TEC. We believe M-TEC is capable of fabricating the light interference fits that metal-to-metal seals require, and we have allocated an adequate initial budget entry in the first year to fabricate a variety of specimens to be tested later in the newly developed test rig. Progress in the first year will provide guidance for subsequent resources devoted to this aspect of the project.

Project schedule

- 1) During the first year, we shall determine the instrumentation necessary to characterize the transient mechanical operation of two or three common pyrovalve designs. These preliminary test specimens, which will be composed of used valves, will be supplied by WSTF. We shall also rely on the systems developed at WSTF the means to simulate the igniter pulse without resorting to explosives while we are developing the measurement system. Later, after our confidence in the system is established, we will verify it in the WSTF laboratory in 'full scale' tests. Also during the first year, we

shall work with the WSTF staff to develop machining techniques appropriate for some of the newer materials recently proposed that may prove promising alternatives to the steels used at present.

- 2) During year two we shall apply the newly developed test rig to gage the effects of corrosion on pyrovalve designs under consideration at Stennis Space Center. We will work closely with Stennis personnel in selecting the specimens and the test protocol.
- 3) In the final year of the project we will devote our attention to advanced pyrovalve designs. This will include primarily the testing of metal-to-metal seal configurations and to the testing of newer, corrosion resistant (e.g., tantalum based) components.

Student Involvement

There's been an understandable need to embrace the new information (i.e., computer) technology in engineering curricula in most public institutions. A result of this competition for the students' time and energy is to diminish the importance of the connection between the virtual and the real worlds. Whether the discipline is Mechanical, Electrical, or other engineering sub-discipline, a similar trend is observed [8].

In typical Mechanical Engineering curricula, for example, we have emphasized the (increasingly potent) finite element software that allows students to analyze stress, fluid flow, and energy transport throughout complicated mechanical systems.

Similarly, in Electrical Engineering, students now universally use tools such as MATLAB to design advanced control systems based on some given specifications such as settling time or overshoot. The origin of such design specifications is typically in the system being controlled - in a winding machine, for example, overshoot or underdamped response results in poor process quality. These insights are difficult to provide without adequate laboratories and cross-disciplinary collaboration.

As a result, many of our engineering students graduate into an unnecessarily strange workplace where they find that their computer's output is merely the beginning, rather than the culmination, of the design process. Increasingly, we academics find ourselves relying on carefully selected research tasks and laboratory experiences which, in my experience,

substantially reduce the disconnect between what students study and the problems they're expected to solve as industry professionals. Thus, the secondary intent of this proposal is to provide training and experience in the research laboratory. The proposed research project is clearly a natural way to re-establish the desired balance.

We also are mindful of our industrial advisors who continually urge that students be given a more extensive 'introduction' to experimentation and data analysis. Clearly the proposed research program provides a convenient approach to ensuring a significant number of graduate students have extensive training in calibration and testing, as well as analysis. We also note that undergraduate students, during their time in school, have limited exposure to this area. Thus a large number of undergraduate students, up to nine, are included in the proposed project.

A final benefit to the collaborators on this project is the significant number of students who will very likely work on this project while not on the NASA budget. Over the years the PI's laboratory has been the focus of many minority students whose research internship was funded by AMP, the New Mexico Alliance for Minority Participation, by the Office of Indian Affairs, housed at NMSU, and at least two additional private foundations. The proposed project continues in the same vein, and provides a unique opportunity the Mechanical Engineering Department at NMSU to participate in institutional and college efforts in recruiting and retaining a diverse student population.

References

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